Deas Slough, Fraser River Estuary, British Columbia: General Description and Some Aquatic Characteristics

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by

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PREFACE

A proposal to maintain and increase the depth of the main shipping channel in the lower Fraser River, by modifying river flows through the installation of training walls, was advanced by Public Works Canada in 1976. In response to this proposal the Department of Fisheries and Oceans carried out studies to provide pertinent information on fish ecology.

The work was carried out in 1976 and 1977 and it focussed upon Tilbury and Deas Sloughs and adjacent estuarine areas. Sloughs were chosen as representative of slackwater areas, similar to those which could be created behind training walls, and also because they could be affected by modified flow regimes.

Fish distribution, abundance and diet were examined, as well as fish survival and use of the water column in in-situ experiments. Sediment and water characteristics were studied, the latter in relation to fish distribution. This report is one in a series which describe the results of these investigations.

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ABSTRACT

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Measurements of certain aquatic variables were made between April 1976 and September 1977 in Deas Slough and adjacent areas of the Fraser River estuary, as part of a fish ecology program.

During the winter low freshwater-flow period, saline intrusion into the estuary resulted in vertical stratification in Deas Slough. Salinities increased progressively as river flow decreased, and values up to 10.3‰ were recorded at depth, and 3.3‰ in surface waters. In spring, freshet conditions reduced saline intrusion, and in residual salt water within deep pockets of the slough hypoxic conditions (less than 5% of air saturation) developed. Thermal stratification occurred, with temperature differences from surface to bottom waters of up to 9.5°C. These effects were greater in upper than in lower Deas Slough, likely reflecting relative differences in the extent of tidal flushing. The range of temperature and dissolved oxygen values was greater in upper Deas Slough than in lower Deas Slough or the adjacent area of Ladner Reach. While mean temperatures were similar in the three areas, mean dissolved oxygen levels were significantly higher in Ladner Reach than in Deas Slough. Temperature increases, from January minima under 1.5°C to August maxima as high as 23.0°C, began earlier in the year in upper Deas Slough than in lower Deas Slough and Ladner Reach, and by April (1977) surface waters in the upper slough were several degrees warmer than elsewhere in the study area.

A decrease in oxidation-reduction potentials (ORP) at depth was associated with the early spring dissolved oxygen depression. Depressed values, to +60 mV and less, at depth, and differences of over +200 mV from surface to bottom, were recorded in Deas Slough. With the progression of freshet, and thereafter, higher and more homogeneous dissolved oxygen and ORP values were recorded throughout the water column.

Water clarity decreased from a January maximum to an April minimum. For example, Secchi disc visibilities of 92cm (January) and 13cm (April) were recorded in lower Deas Slough, reflecting the increased discharge of the Fraser River and associated elevation in suspended solids.

During the times of known utilization of Deas Slough by non-migrant fish populations, the water characteristics measured in this study were generally at levels considered acceptable to fish. However, it is not known where these populations resided during those times of year when stressful or lethal conditions (e.g. hypoxic waters) existed in Deas Slough. The currently more commercially valuable salmonid species occurred in Deas Slough when sub-

optimal conditions often occurred in deeper waters. Under such conditions, fish would be restricted to the surface waters and accordingly the water column would be underutilized.

RESUME

Birtwell, I. K., M. D. Nassichuk, H. Beune, and M. Gang. 1987. Deas Slough, Fraser River estuary, British Columbia: general description and some aquatic characteristics. Can. MS Rep. Fish. Aquat. Sci. 1926: 45 p.

D'avril 1976 à septembre 1977, on a effectué des quantifications de certaines variables aquatiques dans le marais Deas et les zones avoisinantes de l'estuaire du fleuve Fraser dans le cadre d'un programme sur l'écologie du poisson.

Pendant le faible débit d'eau douce en hiver, l'entrée d'eau salée dans l'estuaire a entraîné la stratification verticale du marais Deas. Les salinités ont augmenté progressivement en fonction de la baisse du débit fluvial: des valeurs allant jusqu'à 10,3 0/00 ont été notées dans les eaux profondes et 3,3 0/00 dans les eaux superficielles. Au printemps, la crue a réduit l'entrée d'eau salée et dans certaines dépressions profondes contenant de l'eau salée résiduelle, des conditions hypoxiques (moins de 5% de saturation atmosphérique) se sont développées. On a observé une stratification thermique avec des différences de température entre la surface et le fond allant jusqu'à 9,5°C. Ces effets étaient plus prononcés dans la partie supérieure du marais Deas, ce qui traduit probablement des différences relatives dans l'action des marées. L'écart des températures et des teneurs en oxygène dissous était plus élevé dans la partie supérieure du marais Deas que dans la partie inférieure ou la région avoisinante du goulet Ladner. Les températures moyennes étaient semblables dans ces trois régions, mais les teneurs moyennes en oxygène dissous étaient nettement plus élevées dans le goulet Ladner que dans le marais Deas. L'augmentation de la température, d'un minimum inférieur à 1,5°C en janvier à un maximum atteignant jusqu'à 23,0°C en août, a débuté plus tôt dans la partie supérieure du marais Deas que dans la partie inférieure ou dans le goulet Ladner; dès avril (1977), les eaux superficielles de la partie supérieure du marais Deas étaient plus chaudes qu'ailleurs dans la zone à l'étude.

Une baisse des potentiels d'oxydoréduction (POR) dans les eaux profondes était liée à un abaissement de la teneur en oxygène dissous au début du printemps. Des valeurs diminuées, jusqu'à +60 mV et moins, dans les eaux profondes et des différences de plus de +200 mV entre les eaux superficielles et profondes ont été notées dans le marais Deas. Avec la progression de la crue et par la suite, on a relevé des teneurs en oxygène dissous et des PRO plus élevés et plus homogènes dans toute la colonne d'eau.

De janvier à avril, la clarté de l'eau est passée d'un maximum à un minimum. Ainsi, des visibilités au disque Secchi de 92 cm (janvier) et de 13 cm (avril) ont été notées dans la partie inférieure du marais Deas; ceci traduit une augmentation du débit du Fraser et de la quantité de solides en suspension.

Quand des populations de poisson non migratoires utilisaient le marais Deas, les caractéristiques aqueuses quantifiées étaient généralement à des niveaux considérés acceptables pour les poissons. *Toutefois, on ne* sait pas où ces populations séjournent pendant les périodes de l'année où les conditions (e.g. eaux hypoxiques) dans le marais Deas sont létales ou stressantes. Les espèces de salmonidés qui ont actuellement une plus grande valeur marchande fréquentaient le marais Deas quand des conditions suboptimales étaient souvent présentes dans les eaux profondes. Dans de telles conditions, les poissons étaient restreints aux eaux superficielles et donc la colonne d'eau était sous-utilisée.

INTRODUCTION

This report describes aspects of the aquatic characteristics of Deas Slough and adjacent areas of the Fraser River estuary. The data were gathered during an 18-month investigation (1976, 1977), in which the main objective was to examine fish populations. The information obtained was to be used in an assessment of the effects of proposed "training walls" in the lower Fraser River. This report focuses upon relative changes in temperature, dissolved oxygen, salinity, pH, oxidation-reduction potential, and water clarity in nearshore surface waters and in the water column of Deas Slough: relevant background information is also provided. Other reports describe the studies on fish ecology (e.g., Birtwell et al. 1987).

The Fraser River system

The Fraser River, one of the major rivers in North America, drains the largest watershed in British Columbia (about 233,000 km^2). It provides spawning grounds and rearing and migratory corridors for one of the world's most important salmon fisheries, with a catch valued at about $82,000,000. The lower Fraser River, extending 136 km from Hope to the Strait of Georgia, has little elevation change, with a resultant upstream tidal influence of about 110 km during periods of low river flow (Hodgins, 1974). Large seasonal variations in fresh water flow exist in the watershed, primarily due to the melting of snow in the spring. At Hope, measured flow has ranged from a maximum of 15177$m^3 \cdot s^{-1}$ (536,000 cfs) on May 31, 1948 to a minimum of 340$m^3 \cdot s^{-1}$ (12,000 cfs) on January 8, 1916, with an annual average of 2690 $m^3 \cdot s^{-1}$ (Northcote, 1974).

The estuary of the Fraser River is vertically stratified, and the extent of saltwater intrusion is related to tidal amplitude and river flow. During the winter period of low freshwater-flow, salt water may penetrate about 33 km upstream to New Westminster, but in the late spring, the increased flows may confine this intrusion to the vicinity of the river mouth (Ages, 1979).

Each year, hundreds of millions of juvenile salmon migrate downstream, mainly during the months of March to May, to the lower Fraser River and into the estuary. Although the residency of juvenile salmon has not been fully documented in the lower Fraser River, studies do suggest that certain species reside in the inner estuarine marsh habitats for several days, weeks, or months (Dunford, 1975; Goodman, 1975; Levy et al. 1979; Levy and Northcote, 1981). It has been estimated that the Fraser River drainage basin could produce 73% of British Columbia sockeye, 67% of chinook, 50% of pink, 34% of chum, and 12% of coho salmon if maximum potentials were realized (Department of Fisheries and Oceans, unpublished information).

Development of the lower Fraser River

Development of the Fraser River delta resulted in alienation of former saltmarsh (about 70%, 218 ha.), tidal freshwater marsh (30%, 628 ha.), and flooded habitat (99%, 81 ha.), primarily due to extensive dyking for land

reclamation and flood control (Romaine et al. 1976). The Fraser River estuary, due to its large size and proximity to the high population density of the Greater Vancouver Regional District (GVRD), has sustained changes in land usage involving agriculture, moderate industrial activity, and urban development. Although agricultural land comprises the major portion (22.3%) of the shore length within the Fraser River estuary area, as defined by the Fraser River Estuary Study Steering Committee (FRESSC, 1978), this open space is under continual pressure due to increasing demands for industrial and urban development.

Transportation routes and facilities including roads, railways, and airports comprise the second largest percentage (19.6%) of the upland land use in the delta. Wood preserving, food processing, metal and petroleum industries, and other manufacturing operations utilize an additional 11.6% of the delta's upland area. Other uses include residential (5.3%) and commercial/institutional (2.3%). The remaining 32.5% of upland area includes lakes and dykes, parks, and recreational areas (FRESSC, 1978).

On the North Arm of the Fraser River, the wood processing industry uses 19% of the foreshore area, notably for waterfront mills, log storage, and log sorting. Light industrial uses of the Fraser River waterfront include building material plants, fish processing plants, metal products and machine shops, and some food and plastics industries. These activities utilize approximately 19.2% of the total shoreline in the study area (FRESSC, 1978).

Shipping and navigation in the Fraser River Harbour (South Arm) involves shallow draught and deep sea cargo handling, as well as many small commercial and recreational craft. Channel maintenance and dredging along with permanent training structures are used to maintain a 7.6 m draught to New Westminster. In the past, dredge spoil disposal sites have been located on the foreshore of the lower Fraser River, for example at Steveston Island.

Dyking for flood control and land reclamation in the Fraser River delta was essentially completed by the turn of the century (Romaine et al. 1976). Jetties, causeways, and other structures within the delta have also altered foreshore areas.

Fraser River training walls

A river training wall proposal was designed to modify the navigation channel in the lower reach of the Fraser River from New Westminster to its mouth, to accommodate ships up to a 12.2 m draught (Public Works Canada, 1977). The proposed training structures, of rock and gravel ("rip rap") or creosoted piles (Envirocon Ltd., 1976), would constrict the width of the river channel, thereby increasing water velocities and reducing sedimentation. The net effect would be to make the lower river largely self-scouring. At present, some 2.5 x 10^6 m^3 of material must be dredged annually to maintain navigational depths (Beak Consultants Ltd., 1981).

The training wall proposal generated concern about possible insidious alterations to the biology of the lower Fraser River. Changes in flow, sedimentation, and water quality might result in significant alterations to the floral and faunal composition. Furthermore, only limited information existed regarding the chemical (e.g. Benedict, Hall and Koch, 1973; Hall, Koch and Yesaki, 1974; Joy, 1975) and biological (e.g. Northcote, 1974; Dunford, 1975; Goodman, 1975) characteristics of the lower Fraser River. The Federal Department of Fisheries and Oceans, with Public Works Canada, undertook studies (1976-77) to provide additional physico-chemical and biological data that could be used in assessing the effects of training walls on the ecology and water quality of the lower Fraser River (Beak Consultants Ltd., 1981).

Deas Slough

Deas Slough was studied because it was formerly a side-arm of the Fraser River which was dammed off at its upstream end in 1948, thus creating a backwater area similar to those which could occur behind certain river training structures. The slough is situated in the South Arm of the Fraser River, about 10 km upstream from its mouth at Steveston (Figure 1). It is approximately 2700 m long, 250 m wide, with an average depth of 5 m. Dredged pockets exist in front of the two marinas situated on, and utilizing about one-third of the shore of, the south bank of the slough. A longitudinal profile of the slough is shown in Figure 2. The bottom material in the slough is predominantly silt and clay, while at the adjacent riverine areas it is predominantly sand. The shoreline is fringed by a zone of sedges (Carex sp.), bullrushes (Scirpus sp.), and cat-tails (Typha sp.). The upland vegetation consists of black cottonwood trees (Populus trichocarpa) with an understory dominated by red alder (Alnus rubra) and willow (Salix sp.), and a shrub layer consisting of salmonberry and blackberry bushes (Rubus sp.) as well as salal (Gaultheria sp.) and huckleberry (Vaccinium sp.).

The central part of Deas Island was used for the cultivation of cereal crops during the time of our study, but currently it is a GVRD municipal park. Most of the areas north and south of the slough are farmland (grass, crops). Some of the land is below sea-level, and is intersected by ditches to facilitate drainage.

Crescent Slough drains into Deas Slough from a large area to the east and north of Deas Slough, including Burn's Bog. A 750 m pipe carrying sewage from the Corporation of Delta enters the slough and discharges into the mainstem Fraser River. Components of sewage were present in the water at the mouth of the slough, where gulls frequently feed. The comminuted and chlorinated sewage is mainly of domestic origin, but there is some input from industries within the Corporation of Delta. The discharge varies between 3 and 3.5 million litres per day.

Water characteristics and fish populations in two approximately equal areas of Deas Slough, and in adjacent riverine regions of Woodward and Ladner Reach were compared. Thus three zones comprised the study area (Figure 3).

MATERIALS AND METHODS

A multi-probe sensing unit (Hydrolab Corporation, Model 6D) was used to provide "in-situ" measurements of temperature, conductivity, dissolved oxygen, pH, and oxidation-reduction potential (ORP). Dissolved oxygen content was expressed in $mg \cdot L^{-1}$ and percent of air saturation, using the formula furnished by Gameson and Robertson (1955). The sensing unit was inspected, cleaned, recharged, and calibrated before each sampling occasion. Water clarity was assessed using a 20 cm diameter Secchi disc.

Measurements of the above-mentioned variables were made at 0.5 m depth on every sampling occasion at each of the 12 shoreline sites (4 per zone) used to capture fish (Figure 3), at high and low tide. In addition, the water column was sampled to obtain profile information during high tide at monthly intervals at four sites (Figure 2, 3): measurements were made at 0.5 m, 1 m, and successive 1 m intervals to the bottom.

RESULTS

Temperature

Shoreline sites (0.5 m depth)

Surface water temperatures in the study area reached their highest values at the upper end of Deas Slough (Figure 4). The maximum values recorded were 20.5°C in 1976 (August 18, site 2), and 23.0°C in 1977 (August 3, site 1). In lower Deas Slough, the temperature maxima were 20.0°C in 1976 (August 11, site 6) and 21.4°C in 1977 (August 18, site 5). At the Fraser River sites (9 and 10) temperatures did not exceed 16°C in 1976, whereas at site 12 in Ladner Reach a maximum of 18.6°C was recorded (September 8). However, in 1977, a temperature of 20.2°C was recorded in this zone (August 18, site 9).

The minimum recorded temperatures were on January 10 and 11, 1977: 1.2°C in upper Deas Slough (site 3); 1.3°C in lower Deas Slough (site 7); and 1.4°C in Ladner Reach (site 10).

The least temperature variation occurred in Ladner Reach (Table 1). There were no significant differences in mean temperatures recorded in the three sampling zones, or between mean values at high and low tides (Table 2).

Profile Sites

Thermal stratification occurred in Deas Slough during the low freshwater-flow period preceeding freshet (Figure 5). During the winter of 1975-1976 (November to February), there was little difference in temperature between the bottom saline layer and the overlying fresh water layer. Through the spring, the fresh water layer gradually warmed, contrasting with the saline waters which remained in depressions in upper and lower Deas Slough. For example, on July 29, 1976, the water temperature was 17.4°C at the surface and 7.9°C at the bottom.

Only a thin and relatively transient saline layer entered the slough in the winter of 1976-1977. The maximum temperature difference due to saline stratification in 1977 occurred on April 13, when the temperatures at the surface and bottom were 8.5 and 5.4°C respectively (Figure 5).

Temperature differences between the top and bottom of the water column, without saline stratification, also occurred in Deas Slough, and were most pronounced near the upper end. The maximum observed difference under these conditions was 4.7°C (18.9°C at the surface and 14.2°C at the bottom), recorded on June 7, 1977. Such thermal structures, under isohaline conditions, were ephemeral phemonema: even at the most sheltered locations at the upper end of the slough, the water column appeared to mix readily.

Salinity

Shoreline sites (0.5 m)

Seasonal changes in salinity were recorded, varying, most notably, with river flow conditions (Figure 6). From April to November, 1976 salinities in Deas Slough were 1‰ or less, at all the nearshore sampling sites (0.5 m). During the winter 1976-1977 low flow period, upstream penetration of salt water affected the salinity of the entire water column in Deas Slough. Salinities increased from November through January 1977, thereafter remaining elevated until March. As river flows increased salinities fluctuated, but by May levels were consistently very low.

Overall, there was no significant difference in salinities recorded in the three sampling zones (Table 1). In the autumn of 1976, significant differences were observed between the salinities at high and low tides in the Ladner Reach zone (Table 2). The highest salinities measured in the nearshore area were 5.9‰ at Ladner Reach (January 10, 1977, site 9), and 3.3‰ and 1‰ (March 2, 3, 1977) in lower and upper Deas Slough respectively (Figure 6).

Profile Sites

Salinities up to 26‰ were measured at 8.5 m depth outside Deas Slough. A sill at the mouth of Deas Slough, however, prevented intrusion of water from depths greater than about 4 m, therefore salinities in the slough were equivalent to those at the same depths in adjacent waters of the Fraser River. The maximum salinity recorded on the sill (profile site 4) was 9.7‰ (January 11, 1977 (Figure 7).

Between November and April (1975-1976), salinities were higher at Ladner Reach than at either of the slough zones (Figure 6). Maximum salinities measured in the slough were 10.3‰ and 6.6‰ >4 m depth) in lower and upper Deas Slough respectively, March 2, 1977. Thereafter, salinities decreased, more rapidly in lower, than in upper, Deas Slough; by April 13 and May 13, (in the same zones, respectively) freshwater conditions again prevailed.

During the mild winter of 1976-1977, unusually high freshwater flow conditions resulted in less saline incursion than in the preceding year. By April 13, 1977, the thickness of the saline layer in the deepest part of upper Deas Slough was 1 to 1.5 m, with a salinity of 5.7‰; contrasting with a layer of approximately 3.5 m thickness, with an average salinity of 8‰, on April 29, in 1976. By July 29, 1976, the saline layer (7.5‰) in upper Deas Slough was 2.5 m thick, and thereafter salinities of 6‰ were recorded on August 5 and on September 2. Salinities in this zone decreased to <0.1‰ in late September. In early October, 1977, salinities began to increase again.

Dissolved Oxygen

Shoreline sites (0.5 m)

The mean dissolved oxygen content of surface waters was significantly greater in Ladner Reach (108% of air saturation) than in lower or upper Deas Slough (104% and 99% of air saturation, respectively) for the study period as a whole ($p < 0.05$, Table 1, Figure 8). A significant difference also existed between the mean dissolved oxygen levels at high and low tide in lower Deas Slough (although not in the other zones) (Table 2); dissolved oxygen being greater at high tide ($\bar{x}$ = 105% of air saturation) than at low tide ($\bar{x}$ = 102% of air saturation). Neither of these differences are thought to have biological significance.

Extreme values recorded in upper Deas Slough were 69% and 142% of air saturation, and both were recorded in the uppermost part (sites 1 and 2, November 10, 1976 and April 28, 1977 respectively). In lower Deas Slough values ranged between between 84 and 119% of air saturation (site 6, September 1, and August 4, 1977, respectively). In Ladner Reach, the extremes were 94% and 165% of air saturation, site 12, December 10, 1976 and August 3, 1977, respectively (Figure 8). The extreme values were recorded at the most protected sites in each zone and may have been caused by local photosynthetic activity. Dissolved oxygen values tended to be more variable in upper Deas Slough than in the other sampling zones (Figure 8). The lowest dissolved oxygen value was recorded in upper Deas Slough, probably reflecting the reduced flushing rate of this region relative to the river channel areas.

Similar patterns of seasonal variation in dissolved oxygen levels were noted in the three sampling zones. Maximum mean values for 1976 occurred on August 3 in all three zones (113%, 115%, and 118% of air saturation in Ladner Reach, lower Deas Slough, and upper Deas Slough respectively). A decline in dissolved oxygen levels followed these maxima. The decline began in September in upper Deas Slough, but not until late November in lower Deas Slough and Ladner Reach. Dissolved oxygen levels rose again in spring, (April 28; 118%, 116% and 124%, respectively). Subsequently, dissolved oxygen levels were at air saturation in Ladner Reach and lower Deas Slough, but only 87% of air

saturation in upper Deas Slough (June, July). All values were above saturation on August 3, 1977: 111%, 106%, and 104%, respectively).

Profile sites

At site 4, on the sill at the mouth of Deas Slough, the dissolved oxygen conditions varied little, vertically or seasonally (Figure 9). In the period from December 1976 to November 1977, recorded values ranged from 95% to 111% of air saturation at 0.5 m depth, and 90% to 111% of air saturation at 3.5 to 4.0 m depth.

At sampling station 3, over the deepest point in lower Deas Slough, the oxygen saturation values varied little, seasonally, in surface waters (93% to 108% of air saturation), but more so at depth (7 m, 68% to 104% of air saturation) (Figure 12). The dissolved oxygen values near the bottom were 85% of air saturation on December 10, 1976; 80% on January 11, 1977; 68% on February 9, 1977 and also on March 2, 1977. These values were recorded in more saline waters. On March 31, 1977, dissolved oxygen values were from 93% to 104% of air saturation, similar to values in surface waters, and remained close to saturation until the end of the sampling period (Figure 9).

At water profile site 2, over the deep pocket in upper Deas Slough, the dissolved oxygen values ranged between 83% and 107% of air saturation near the water surface. Near the bottom, at 10 to 11 m depth, however, the conditions ranged widely from about 1% to 92% of air saturation. Dissolved oxygen near the bottom was 90% of air saturation on December 10, 1976 80% on January 11, 60% on February 9, and 77% on March 2, 1977. During this time, salinity increased in the deepwater pocket (Figure 7). After March 2, the salinity of water in the deep pocket decreased slowly, indicating little exchange between the saltwater and overlying freshwater layers. As mixing of the two layers occurred very slowly, dissolved oxygen levels in the saline water began to drop as soon as the connection with the Fraser River salt-wedge was, presumably, lost. Values near the bottom decreased from 77% of air saturation on March 2 to 14% of air saturation on March 31, to approximately 1% of air saturation on April 13, 1977. By May 13, with the progression of freshet conditions, saltwater was absent in the deep waters, and the dissolved oxygen content returned to substantially higher values (83% of air saturation, May 13; 78%, June 7; 92%, July 5; 90%, August 3; and 90% on September 1, 1977).

By October 5, 1977, saltwater intrusion into Deas Slough had again occurred (Figure 7), and a reduction of dissolved oxygen ensued in the deeper water, for example, 82% of air saturation on October 5, 75% on November 3, 1977 (Figure 9).

As previously mentioned, the mild 1976-1977 winter and the associated above-average river discharge probably hindered saline incursion into the estuary and Deas Slough. Thus, mixing of the water column may have been facilitated in 1977, with consequent effects on dissolved oxygen levels in the deeper waters. In 1976, saltwater in the deep pocket at profile station 2 remained until September; waters 0.5 m above the bottom were anoxic on August

19, and had 0.7 $mg \cdot L^{-1}$ dissolved oxygen (8% of air saturation) on September 21, and 9.1 $mg \cdot L^{-1}$ dissolved oxygen (83% of air saturation) on October 5, 1976.

At profile site 1, near the upper end of Deas Slough, the dissolved oxygen measurements ranged from 55% to 116% of air saturation near the surface (0.5 m depth), and 66% to 94% of air saturation at the bottom (4.0 m depth). During November through February, 1977, there was only a 1% to 3% difference in dissolved oxygen content between the top and bottom of the water column on any one sampling occasion, yet values ranged from 75% to 93% of air saturation during this time. During March, April, and May, the water at the bottom was 9 to 12% less saturated than surface water (range: 89% to 97% of air saturation). In June to August, values rose to 104-116% of air saturation at 0.5 m depth, while the dissolved oxygen levels at the bottom remained at 76-87% of air saturation. The largest difference (83% of air saturation at the bottom, 116% at the surface) occurred on June 7, 1977, when the largest temperature difference was also observed. In September and October, the dissolved oxygen content was relatively low at the upper end of the slough, at 0.5 m depth (77% and 55% of air saturation, respectively).

pH

Shoreline sites (0.5 m)

At the shoreline sampling sites in upper Deas Slough, pH values ranged between 6.70 and 8.20 (October 7, 1976, site 4 and September 1, 1976, site 2, respectively) (Figure 10). In lower Deas Slough, pH varied from 6.43 to 8.12 (May 12, 1977, site 5 and June 20, 1977, site 8, respectively). In Ladner Reach, pH extremes were 6.67 and 8.19 (May 24, 1977, site 10 and June 20, 1977, site 11 respectively).

Although the three ranges of pH values are similar, there were significant ($p < 0.05$) differences among means for the zones (Table 1). Ladner Reach had the highest mean pH (7.65) followed by lower Deas Slough (7.53), and upper Deas Slough (7.40). In Ladner Reach and lower Deas Slough, but not in upper Deas Slough, the pH was significantly higher at high tide than at low tide (Table 2). The mean values were (upper Deas Slough, lower Deas Slough, Ladner Reach, respectively): high tide: 7.5, 7.7, 7.7; low tide: 7.4, 7.2, 7.5.

Comparison of Figures 8 and 10 shows the close similarity in pattern of seasonal pH variation with measurements of dissolved oxygen. Only during freshet (late April to early August) is the similarity distorted. During the early half of freshet (late April to mid-June) pH was depressed, and during the latter half (mid-June to early August) it was elevated.

Profile sites

The difference in pH between the bottom and surface of the water column

was very slight in the Deas Slough area; the maximum difference was 0.6 of a pH unit (Table 3).

At water profile station 4, the maximum recorded difference between surface and bottom was 0.3 of a pH unit, observed both on January 11 and June 11, 1977. Dissimilarities in pH between in- and out-flowing water could have caused these minor pH differences.

At site 3, the maximum difference was 0.4 of a pH unit (March 2, 1977), coincident with maximum salinity levels near the bottom. At site 2 the maximum observed difference was 0.6 of a pH unit (April 13, 1977), and, similar to the situation in lower Deas Slough, it was also the date that maximum salinity levels were recorded at this site.

At site 1, the maximum difference was 0.4 of a pH unit, recorded on December 10, 1976, and June 7, 1977. On the latter date, the temperature differential between surface and bottom waters was also at its maximum.

Oxidation-Reduction Potential

Shoreline sites (0.5 m)

The range of oxidation-reduction potentials measured at the shoreline sampling sites varied widely, but there was little difference between the ranges and no significant differences between mean values for the three sampling zones (Figure 11, Table 1). In upper Deas Slough, values ranged from +90 to +360 mV ($\bar{x}$ = +260 mV). In lower Deas Slough, values varied between +75 and +340 mV ($\bar{x}$ = +265 mV), and in Ladner Reach they ranged from +40 to +350 mV ($\bar{x}$ = +265 mV).

There was no significant correlation between ORP values and tidal state (Table 2). The mean high and low tide values, respectively, were +252 and +235 mV in upper Deas Slough, +237 and + 249 mV in lower Deas Slough, and +255 and +254 mV in the Ladner Reach zone.

Seasonal patterns in the three sampling zones were similar. The ORP values were low in winter (about +150 to +200 mV, December and January), then rose slightly (mean values were +200 to +250 mV in mid-February), then decreased again. The lowest values recorded for the year were: +90 mV on February 11, upper Deas Slough; +75 mV, March 2, lower Deas Slough; and +40 mV on March 3 in Ladner Reach. Considerably higher values were recorded in March and April (+300 mV, April 14, upper Deas Slough; +320 mV, March 31, lower Deas Slough and Ladner Reach), but the lowest values for the remainder of the year were also recorded in April in all zones (+145 mV, April 28, upper Deas Slough; +180 mV, April 14, lower Deas Slough; and +125 mV, April 13, Ladner Reach). ORP values at all three zones were at a maximum in September (Figure 11).

Variability of ORP values among sampling zones was less after April. Maximum ORP values were recorded on the last sampling occasion of 1977

(September 16) in Ladner Reach (+350 mV), and on the sampling period immediately preceding that (September 1-2) in upper and lower Deas Slough (+360 mV and +340 mV respectively, Figure 11).

Profile sites

The ORP measurements at the profile sites exhibited a seasonal pattern which reassembled that at the nearshore sampling sites (Figures 11, 12). This pattern consisted of low (+130 to +170 mV) winter values, which rapidly increased to values of +270 to +300 mV by early to late March. A trend of increasing ORP values occurred throughout the summer, reaching an autumn maximum which exceeded the spring value by +80 to +110 mV. The wide fluctuations of ORP noted at the shoreline sites in the spring were not recorded at the water profile sites, except on June 7, when values of +130 to +170 mV were recorded.

At the entrance to Deas Slough (site 4) the surface and bottom values never differed by more than +20 mV.

At site 3, the ORP values at the surface increased from the winter minimum as follows: (December-January) +170 mV, (February 9) +250 mV, (March 2) +270 mV, (March 31) +300 mV. At the bottom of the water column, the following values were recorded: (January 11) +145 mV, (February 9) +140 mV, (March 2) +145 mV, (March 31) +310 mV. The ORP at the bottom remained relatively low about 2 months later than the surface values, and then rose rapidly. This coincided with mixing of the deeper salt water layer with overlying fresh water: on March 2, salinity was 10.3‰, and dissolved oxygen was at 68% of air saturation; but on March 31 salinity was 5.6‰, and dissolved oxygen had returned to near saturation (93%). On all other sampling occasions, the ORP measurements at the top and bottom of the water column at station 3 were within +20 mV.

At site 2, stagnation of the bottom water layer seemed to occur in two stages. ORP at the bottom of the water column was +140mV on January 11, and +160 mV on February 9, 1977. These values were +10 and +40 mV respectively less than the surface values. Dissolved oxygen levels were also reduced (80% to 60% of air saturation on the same dates, respectively). Renewed intrusion of saltwater raised the salinities to their maximum recorded values for 1977 (6.6‰) by March 2. This also raised the dissolved oxygen levels to 70% of air saturation, and produced more homogeneous ORP values from surface to bottom waters (+200 mV). By March 31, 1977, severe reductions in dissolved oxygen concentrations had occurred in the saline water at site 2 (14% of air saturation), but the ORP remained at +300 mV, +20 mV higher than the surface value. However, when dissolved oxygen levels dropped to about 1% of air saturation at the bottom of the water column on April 13, ORP values also reached a minimum of +55 mV (+220 mV lower than the surface value). On the next sampling occasion (May 13) saline incursion had occurred, and dissolved oxygen values at the bottom had risen to 83% of air saturation. The ORP values at this time were +300 mV from the water surface to the bottom.

On June 7 there was a small difference (+25 mV) between the surface and bottom measurements, but on July 7, the next sampling occasion, the difference was substantial (+315 mV at the surface, +250 mV at the bottom). There were no coincident large differences in salinity, temperature, or dissolved oxygen measurements to indicate vertical stratification. On subsequent sampling dates in 1977, vertical differences in ORP values recorded at station 2 were less than +5 mV, within the range of instrument error.

At site 1, in shallower water, ORP values (surface to bottom) varied little, and were within the range of instrument error on all but two sampling occasions: on March 2 and June 7, 1977, the ORP values at the bottom exceeded those at the surface by +25 mV and +35 mV respectively. These ORP differences may have been related to vertical stratification of the water column, since salinity differences, and temperature differences, were maximal on March 2 and June 7, respectively.

Water Clarity

Shoreline sites (0.5 m)

Mean visibility of the Secchi disc was significantly greater in upper Deas Slough ($\bar{x}$ = 58 cm depth), than in lower Deas Slough ($\bar{x}$ = 45 cm) or Ladner Reach ($\bar{x}$ = 45 cm) (Table 1). At the sampling sites in Ladner Reach, water clarity was significantly ($p < 0.05$) greater at high tide than at low tide ($\bar{x}$ = 46 vs. 39 cm) (Table 2). However, pronounced high and low tide differences in water clarity were not observed in the slough.

A seasonal pattern in water clarity was evident at Ladner Reach, in lower Deas Slough, and to a lesser extent in upper Deas Slough (Figure 13). In 1976, water clarity gradually increased to winter maxima of 83 cm, January 10, and February 11, in Ladner Reach and 92 cm in lower Deas Slough (January 10, 1977), and 88 cm in upper Deas Slough (February 11, 1977). Values decreased to minima for the study period, on April 13 and 14 in Ladner Reach (17 cm), lower Deas Slough (13 cm), and upper Deas Slough (27 cm). After this time, water clarity increased, initially very slowly in the Ladner Reach zone and most rapidly in upper Deas Slough (Figure 13).

High Secchi disc visibility readings for 1977 were recorded on August 19 in upper Deas Slough (106 cm depth), and on September 16 in lower Deas Slough (78 cm), and Ladner Reach (80 cm).

DISCUSSION

The values of many physico-chemical variables varied seasonally, and especially in relation to tidal action and river flow. Saline influence, with associated effects on chemical (Malick et al. 1985) and biological (Levings, 1980) characteristics of aquatic habitats, is typical of backwater areas near the Fraser River mouth (e.g. Tilbury Slough, Deas Slough, Ladner Marsh). Saltwater intrusion during the winter low freshwater-flow period resulted in vertical stratification of the water column in Deas Slough, and salinities,

especially at depth, increased progressively as freshwater flows decreased. Levels up to 10.3‰ at the bottom of the slough and 3.3‰ in surface waters were recorded during winter months. A sill at the mouth of Deas Slough prevented saline penetration from depths over 4 m, however, and salinity in the slough never reached the 26‰ bottom, and 5.9‰ surface levels recorded at river sites just outside the slough.

At the onset of freshet, increased river water flow reduced salt water intrusion, and in the deep water pockets of Deas Slough, hypoxic conditions (dissolved oxygen levels down to 1% of air saturation) ensued rapidly in residual saline water, isolated from the salt-wedge of the river. Water chemistry studies in Tilbury Slough (Nassichuk et al. 1984) also revealed the development of hypoxic conditions likely to be harmful to aquatic life (<1.0 $mg \cdot L^{-1}$), but they occurred at a different time of year. The absence of deep dredged pockets which can retain denser saline water could account for the first of these differences, and seasonal variations in the extent of flushing of Tilbury Slough due to tidal action may account for the second (Tilbury Slough can dry on some low tides). In surface waters in Deas Slough, and lower Tilbury Slough, dissolved oxygen levels fluctuated but were generally high, typically at levels considered to confer a high degree of safety to mixed fish communities (Davis, 1975). Dissolved oxygen levels that protect marine anadromous fish species including salmonids appear to be the most desireable for the fish populations of the Fraser River estuary. For these fish, criteria are: Level A, $9 \cdot 0\ mg \cdot L^{-1}$; B, $6 \cdot 5 mg \cdot L^{-1}$; C, $4 \cdot 0$ $mg \cdot L^{-1}$ corresponding to 100%, 79-87% and 57% of air saturation respectively. Level A would provide maximum protection, whereas at level C a large portion of a given fish population or community would be adversely affected: the effect may be severe if the oxygen minimum is prolonged beyond a few hours. Dissolved oxygen levels below Davis' (1975) level C criterion were recorded in the deeper waters of Deas Slough. Thus, full use of the water column would not have occurred at times of hypoxic conditions in the deeper water. Supporting this conclusion are the results of in-situ bioassay experiments in this area, in which all juvenile chum and chinook salmon died within 24h when placed in cages at 8·5m depth in upper Deas Slough (Department of Fisheries and Oceans, unpublished information). Dissolved oxygen levels (5% of air situation) were lethal at this time.

A water characteristics survey carried out between 1975 and 1981 (Malick, et al. 1985) in the Fraser River estuary at the start of spring freshet, determined that sloughs, in general, had lower dissolved oxygen levels than channel sites sampled at the same time. This effect was attributed to the presence of salt water, higher temperatures, reduced flushing rates, and deposited materials with an oxygen demand. Significant variations in dissolved oxygen levels among the sites, and between years were recorded in Deas Slough: similar variations in the Fraser River estuary were also recorded by Malick et al. (1985).

Associated with the dissolved oxygen depression in bottom saline water in Deas Slough was a reduction in oxidation-reduction potentials. Values in

deeper water were observed to differ from surface values by over +200 mV. However, with the progression of freshet, ORP values at depth rose to levels recorded at the surface, as breakdown of vertically stratified conditions occurred.

Although ORP is a complex index with inherent difficulties of interpretation, it has been used as a measure of the relative proportions of autotrophic and heterotrophic activity (Wetzel, 1975). Changes in ORP values in Deas Slough may be due to the relative abundance of zooplankton and phytoplankton, and the gradual increase in ORP observed in Deas Slough during the summer may be related to photosynthetic activity. Associations between ORP and salinity, and reduced dissolved oxygen values have been previously reported in the Fraser River estuary (Malick et al. 1985).

Vertical thermal stratification occurred in the study area in response to saltwater intrusion, and in April a maximum difference of 3.1°C was reported between surface waters and those at depths. During the study period, surface temperature ranges varied from 1.2-23.0°C in upper Deas Slough, to 1.4-20.2°C in Ladner Reach. While the upper slough had the most extreme conditions, no significant differences were noted between the means for the three zones. Maximum and minimum temperature extremes were noted at all sites in August and January. Slough temperatures were higher than those measured at Ladner Reach during the late spring freshet period, and it is possible that this may contribute to attracting fish to the slough.

Measured pH values in the study area ranged from 6.43 to 8.20, with mean values significantly higher at Ladner Reach than either of the slough sampling zones. This is consistent with the findings of Malick et al. (1985), and may reflect the influence of seawater with typically higher pH. Patterns of pH variation corresponded to those of dissolved oxygen, except during freshet. All recorded pH values were in a range considered acceptable to aquatic life (approximately 6.4-8.2) Hoglund (1961).

The seasonal pattern of Secchi disc visibility in Ladner Reach and lower Deas Slough reflects the discharge of the Fraser River and associated changes in the amount of suspended solids. In upper Deas Slough, this effect is less pronounced. Greater water clarity there is likely due to reduced water movement, allowing the settling of suspended material: erratic fluctuations in this zone indicate that other factors, such as localized plankton blooms or an influx of water through drainage channels, may also affect water clarity.

Overall, average recorded values of water characteristics were compatible with fish survival during the observed periods of fish utilization. However, severe oxygen depletion in deep water areas of Deas Slough resulted in dissolved oxygen levels known to be lethal to most fish species; and occasionally, transient but nonetheless stressful conditions prevailed in the shallower waters. Deteriorated water quality conditions of anthropogenic origin (e.g. resulting from dredging at the marinas, sewage, log storage) could exacerbate existing stressors for the species utilizing Deas Slough. For example, recent work by Levy et al. (1985) documented severe oxygen

depletion in Babine Lake due to log storage activities, which reduced fish utilization of the nearshore log storage area. Migratory fish species such as salmon are found in the slough during early spring, before freshet, and may encounter sub-optimal conditions in the water column. In view of the large numbers of fish which use Deas Slough, it is imperative that water quality conditions are not permitted to deteriorate.

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TABLE 1: The results of Analysis of Variance and Duncan's Multiple Range Test applied to water characteristics data, collected at high tide at shoreline sites within three zones of the Deas Slough study area, between 8 August 1986 and 18 September 1977.

Variable	UPPER DEAS SLOUGH (Zone A) n	$\bar{x}$	S.D.	LOWER DEAS SLOUGH (Zone B) n	$\bar{x}$	S.D.	LADNER REACH (Zone C) n	$\bar{x}$	S.D.	Homogeneous Data Subsets
Temperature (°C)	90	13.7	5.52	92	12.5	5.11	92	12.1	5.03	(A, B, C)
Salinity (‰)	86	0.2	0.24	90	0.3	0.56	92	0.4	0.94	(A, B, C)
Dissolved oxygen ($mg \cdot L^{-1}$)	86	10.1	1.73	90	11.0	1.61	92	11.4	1.37	A-(B,C)*
Dissolved oxygen (% air satn.)	86	99	13.8	90	105	6.1	92	108	4.4	A-B-C*
pH	89	7.4	0.32	90	7.5	0.29	91	7.7	0.28	A-B-C*
ORP (mV)	89	263	64.0	92	267	51.1	92	270	56.6	(A, B, C)
Secchi disk visibility (cm)	88	62	21.5	88	45	17.2	88	44	18.3	(C, B)-A*

* $p < 0.05$

TABLE 2. The results of a t-test applied to water quality data, collected at shoreline sites within the Deas Slough study area, at high and low tide, between 8 August and 20 November 1976.

VARIABLE	ZONE	HIGH TIDE n	HIGH TIDE $\bar{x}$	HIGH TIDE S.D.	LOW TIDE n	LOW TIDE $\bar{x}$	LOW TIDE S.D.
Temperature (°C)	Upper Deas Slough (4)	24	15.1	3.60	17	14.7	4.45
	Lower Deas Slough (5)	24	13.9	3.02	19	15.0	3.76
	Ladner Reach (6)	24	13.6	2.82	23	13.8	3.22
Salinity (‰)	Upper Deas Slough (4)	20	0.1	0.00	17	0.2	0.12
	Lower Deas Slough (5)	22	0.1	0.03	19	0.1	0.07
	Ladner Reach (6)	24	0.1	0.12	23	0.1	0.05*
Dissolved oxygen ($mg \cdot L^{-1}$)	Upper Deas Slough (4)	20	10.0	1.29	17	10.2	1.23
	Lower Deas Slough (5)	22	10.8	0.86	19	10.1	1.04*
	Ladner Reach (6)	24	11.0	0.80	23	11.1	0.77
Dissolved oxygen (% satn.)	Upper Deas Slough (4)	20	103	15.2	17	104	16.4
	Lower Deas Slough (5)	22	107	2.9	19	102	4.4*
	Ladner Reach (6)	24	109	3.2	23	110	4.1
pH	Upper Deas Slough (4)	23	7.5	0.34	17	7.4	0.47
	Lower Deas Slough (5)	22	7.7	0.17	19	7.2	0.30*
	Ladner Reach (6)	23	7.7	0.11	23	7.5	0.13*
ORP (+mV)	Upper Deas Slough (4)	23	252	30.1	17	234	29.7
	Lower Deas Slough (5)	24	234	25.5	19	249	25.2
	Ladner Reach (6)	24	257	25.7	23	254	29.7
Secchi disk visibility (cm)	Upper Deas Slough (4)	24	63	15.6	15	64	16.7
	Lower Deas Slough (5)	21	48	15.3	14	47	16.1
	Ladner Reach (6)	20	47	11.8	19	39	13.9

* Significant differences ($P \leq 0.05$)

TABLE 3. Range of pH values at profile sites in Deas Slough, from July 29, 1986 to November 3, 1977.

DATE	SITE	1 DEPTH (m)		2 DEPTH (m)		3 DEPTH (m)		4 DEPTH (m)
1976								
Jul. 29	Min 7.3	4.0	7.0	9.5	7.4	0.5	7.7	4.0
	Max 7.5	0.5	7.4	4.0	7.7	7.6	7.8	5.5
Oct. 15	Min 7.5	3.0	7.8	6.0	7.9	6.0	7.7	0.5
	Max 7.7	0.5	8.0	0.5	8.1	0.5	7.8	4.4
Dec. 10	Min 6.7	2.0	6.9	6.0	7.0	5.0	7.2	0.5
	Max 7.1	3.0	7.2	2.0	7.3	0.5	7.4	3.9
1977								
Jan. 11	Min 7.2	0.5	7.5	12.0	7.6	8.0	8.0	0.5
	Max 7.4	4.0	7.8	2.0	7.9	2.0	8.3	1.0
Feb. 9	Min 7.5	0.5	7.4	2.0	7.6	7.8	7.6	0.5
	Max 7.6	2.0	7.6	8.0	7.6	0.5	7.6	4.3
Mar. 2	Min 7.2	1.0	7.4	3.0	7.3	7.0	7.7	3.4
	Max 7.2	3.0	7.5	0.5	7.7	3.0	7.8	1.0
Mar. 31	Min 7.2	0.5	6.9	10.0	7.3	0.5	7.5	0.5
	Max 7.1	1.0	7.3	1.0	7.5	4.0	7.6	2.8
Apr. 13	Min 7.3	0.5	7.0	10.0	7.7	0.5	7.8	1.0
	Max 7.4	3.5	7.6	1.0	7.8	4.5	8.0	3.0
May 13	Min 7.0	3.0	7.0	0.5	7.3	0.5	7.4	0.5
	Max 7.2	0.5	7.1	10.0	7.4	7.0	7.6	3.0
Jun. 7	Min 7.4	3.0	7.4	0.5	7.3	0.5	7.6	0.5
	Max 7.8	0.5	7.5	6.0	7.7	7.0	7.9	3.0
Jul. 5	Min 7.5	1.0	7.7	0.5	7.6	0.5	7.9	0.5
	Max 7.7	2.0	7.8	10.3	7.9	7.0	8.0	3.0
Aug. 3	Min 7.1	3.0	7.3	0.5	7.3	0.5	7.7	0.5
	Max 7.4	0.5	7.4	9.0	7.6	5.0	7.8	3.5
Sep. 1	Min 7.0	1.0	7.2	0.5	7.5	0.5	7.4	0.5
	Max 7.0	3.0	7.3	10.0	7.5	7.0	7.6	3.0
Oct. 5	Min 7.3	0.5	7.6	0.5	7.8	5.0	7.9	0.5
	Max 7.4	4.0	7.7	9.0	8.0	1.0	8.0	3.0
Nov. 3	Min 7.2	1.0	7.4	10.0	7.4	5.0	7.6	3.0
	Max 7.2	2.0	7.5	1.0	7.6	0.5	7.6	0.5

FIGURE 1. Location of the study area, within the Fraser River estuary, British Columbia.

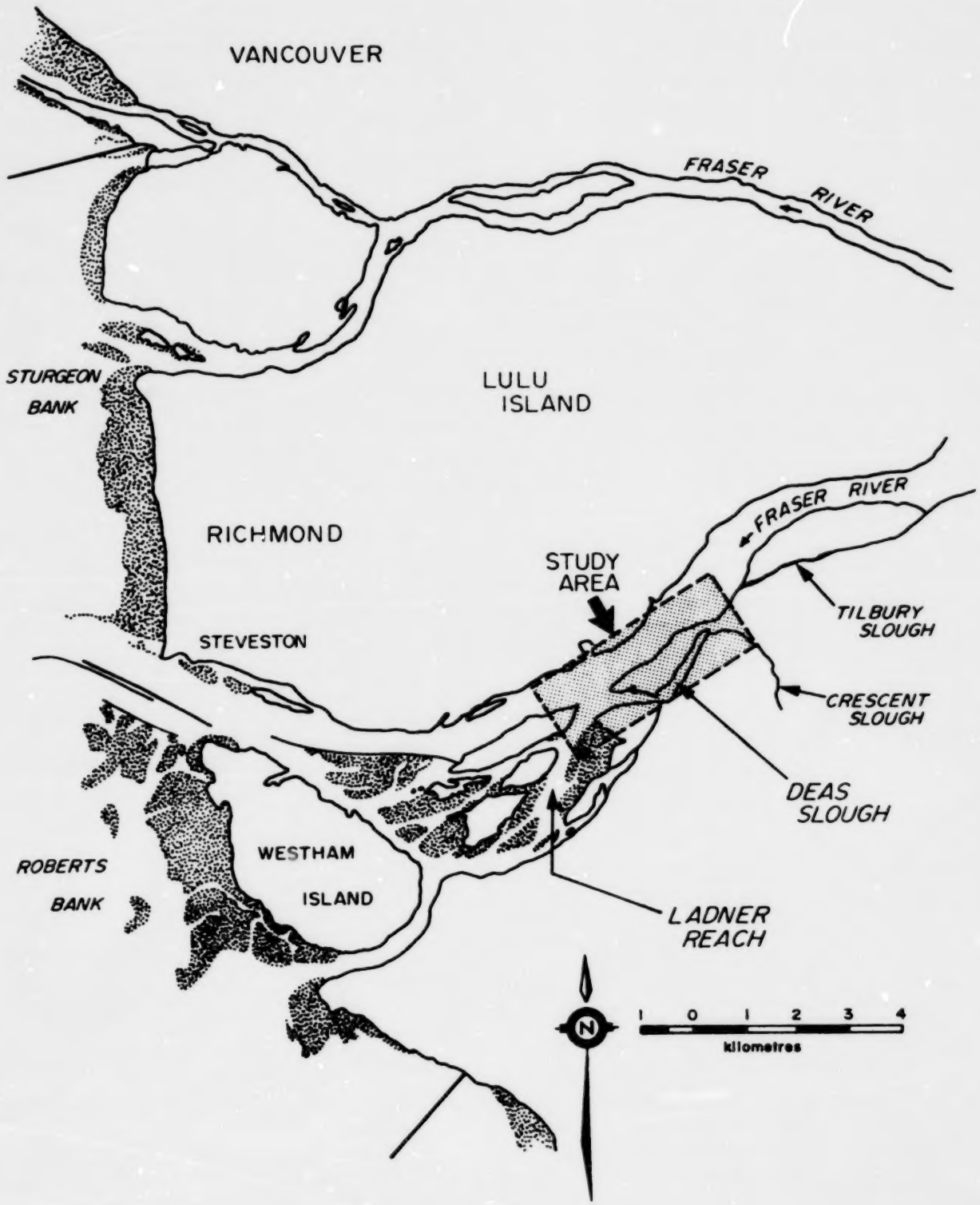

VANCOUVER
FRASER RIVER
STURGEON BANK
LULU ISLAND
RICHMOND
FRASER RIVER
STUDY AREA
TILBURY SLOUGH
STEVESTON
CRESCENT SLOUGH
DEAS SLOUGH
WESTHAM ISLAND
ROBERTS BANK
LADNER REACH
N
1 0 1 2 3 4
kilometres

FIGURE 2. Longitudinal profile of Deas Slough and the location of water quality sampling sites (1-4).

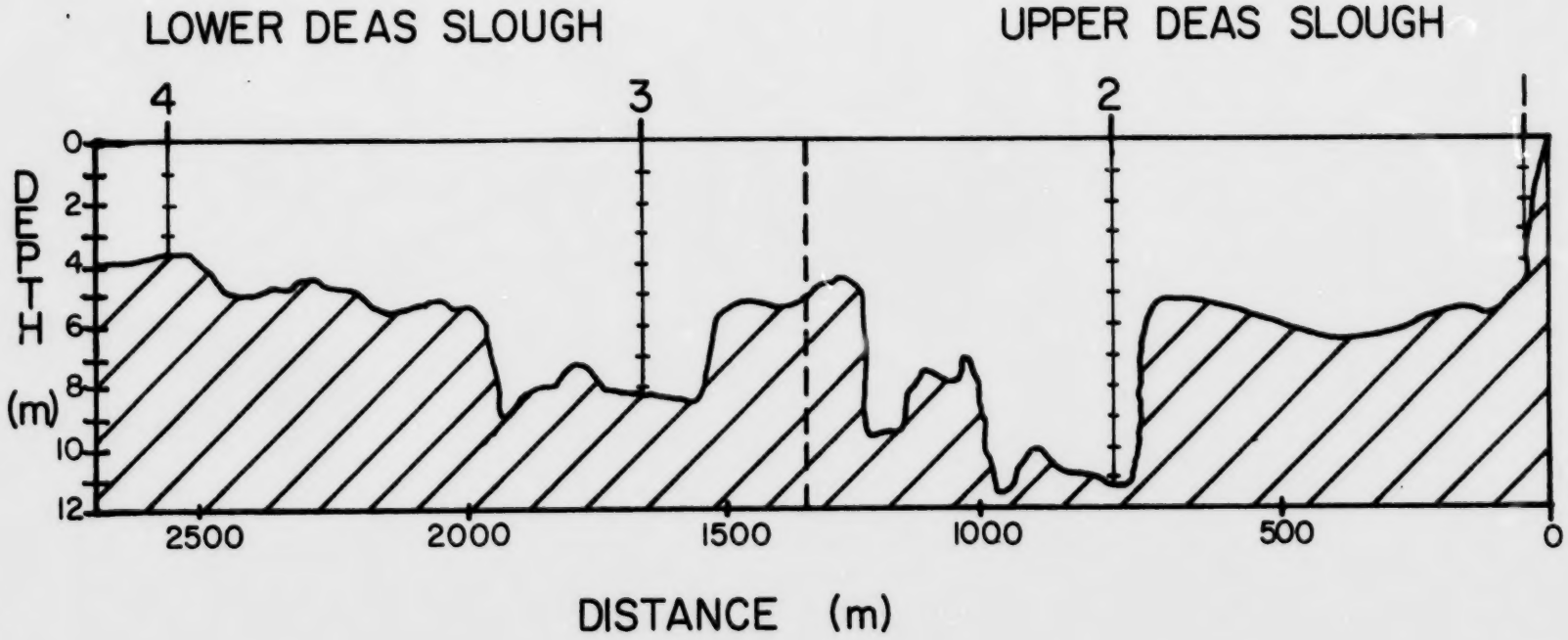

LOWER DEAS SLOUGH
UPPER DEAS SLOUGH
4
3
2
1
0
2
4
6
8
10
12
DEPTH (m)
2500
2000
1500
1000
500
0
DISTANCE (m)

FIGURE 3. Sampling sites in the Deas Slough study area.

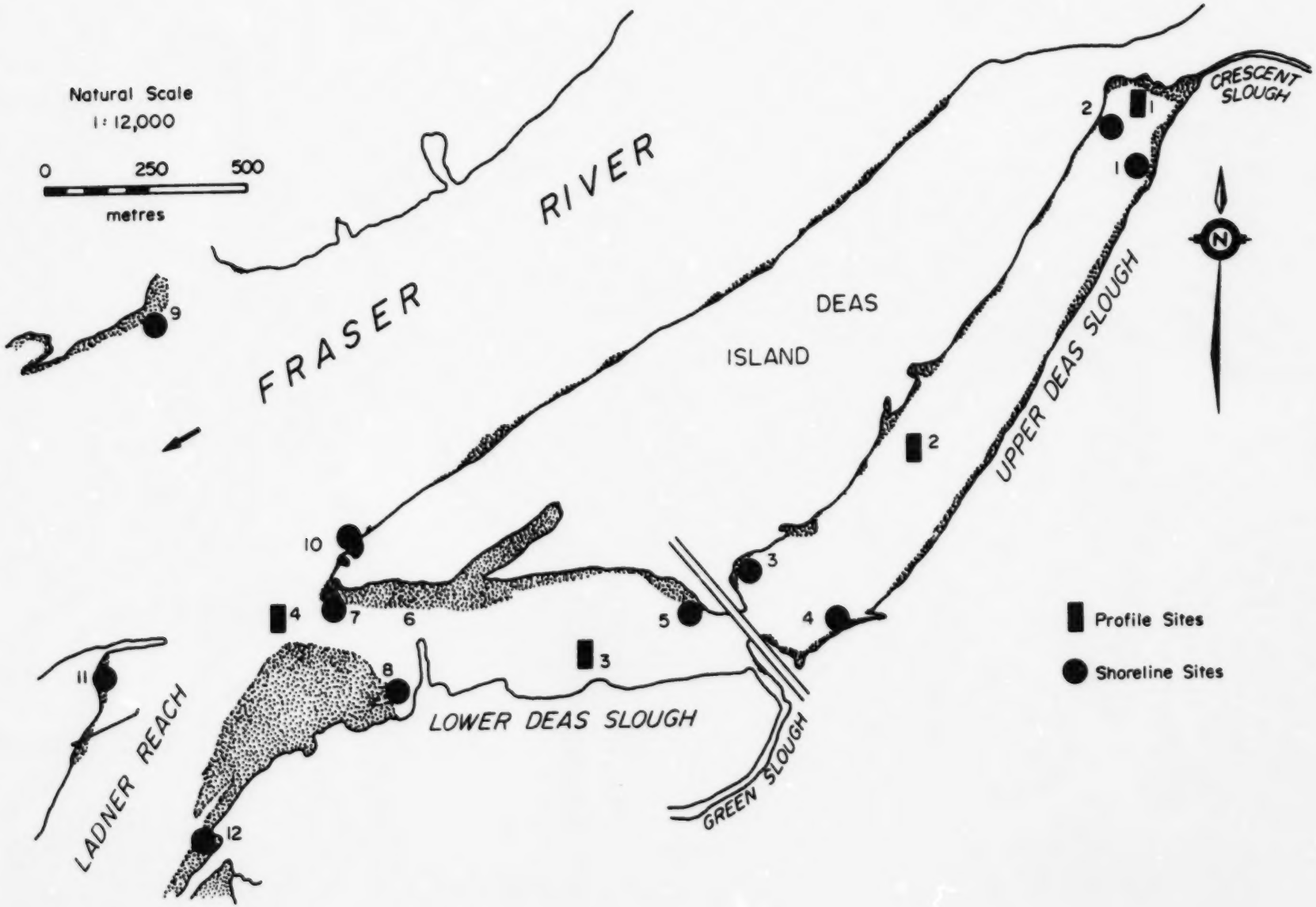

Natural Scale
1 : 12,000
0 250 500
metres
FRASER RIVER
DEAS ISLAND
CRESCENT SLOUGH
UPPER DEAS SLOUGH
LOWER DEAS SLOUGH
GREEN SLOUGH
LADNER REACH
N
Profile Sites
Shoreline Sites

FIGURE 4. Temporal changes in mean temperature values (°C) recorded at 0.5m depth, in two regions of Deas Slough and in the Ladner Reach sampling zone.

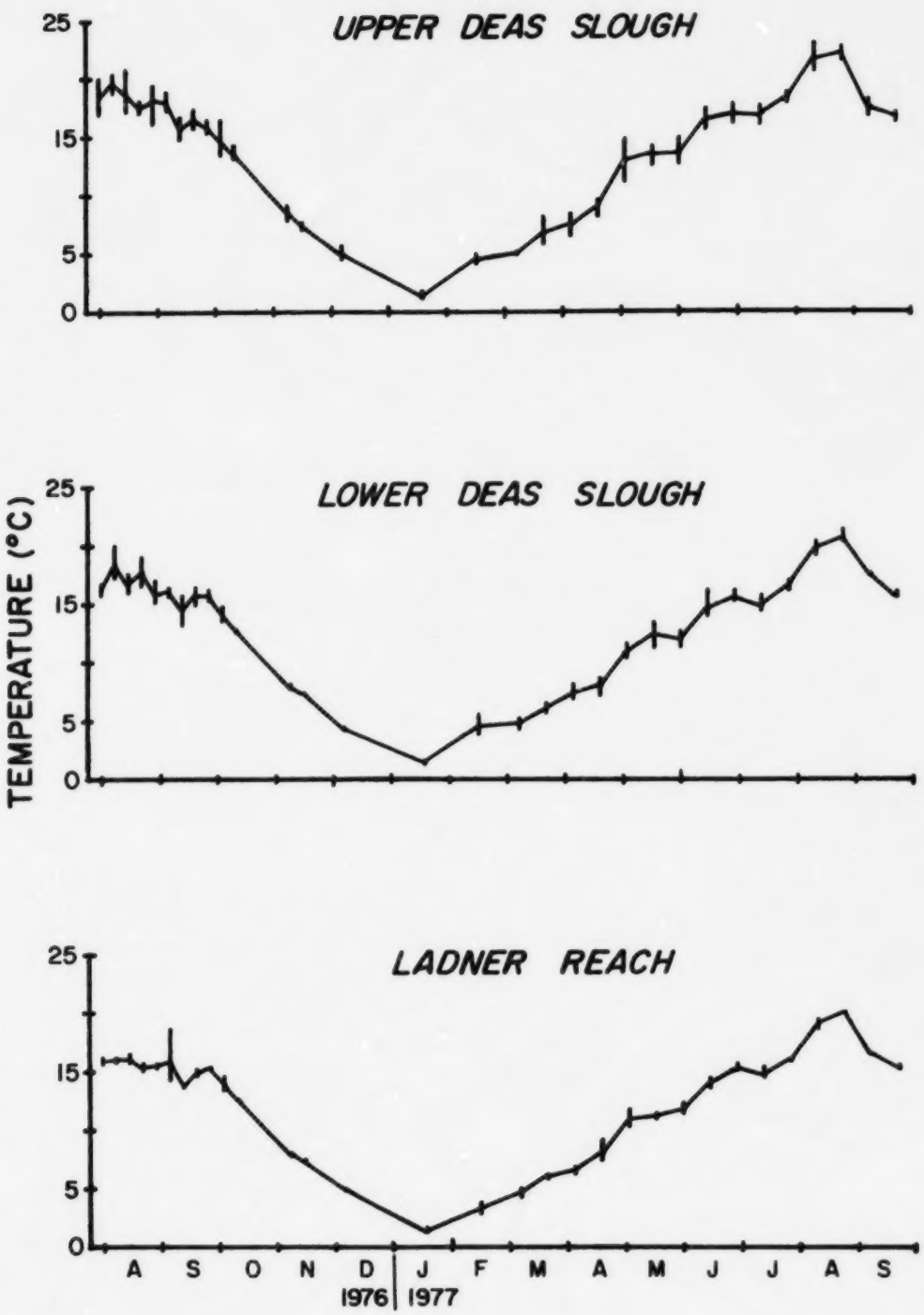

UPPER DEAS SLOUGH
LOWER DEAS SLOUGH
LADNER REACH
TEMPERATURE (°C)
25
15
5
0
A S O N D J F M A M J J A S
1976 1977

FIGURE 5. Isometric-orthographic projection of temperature data collected at 4 sites in Deas Slough.

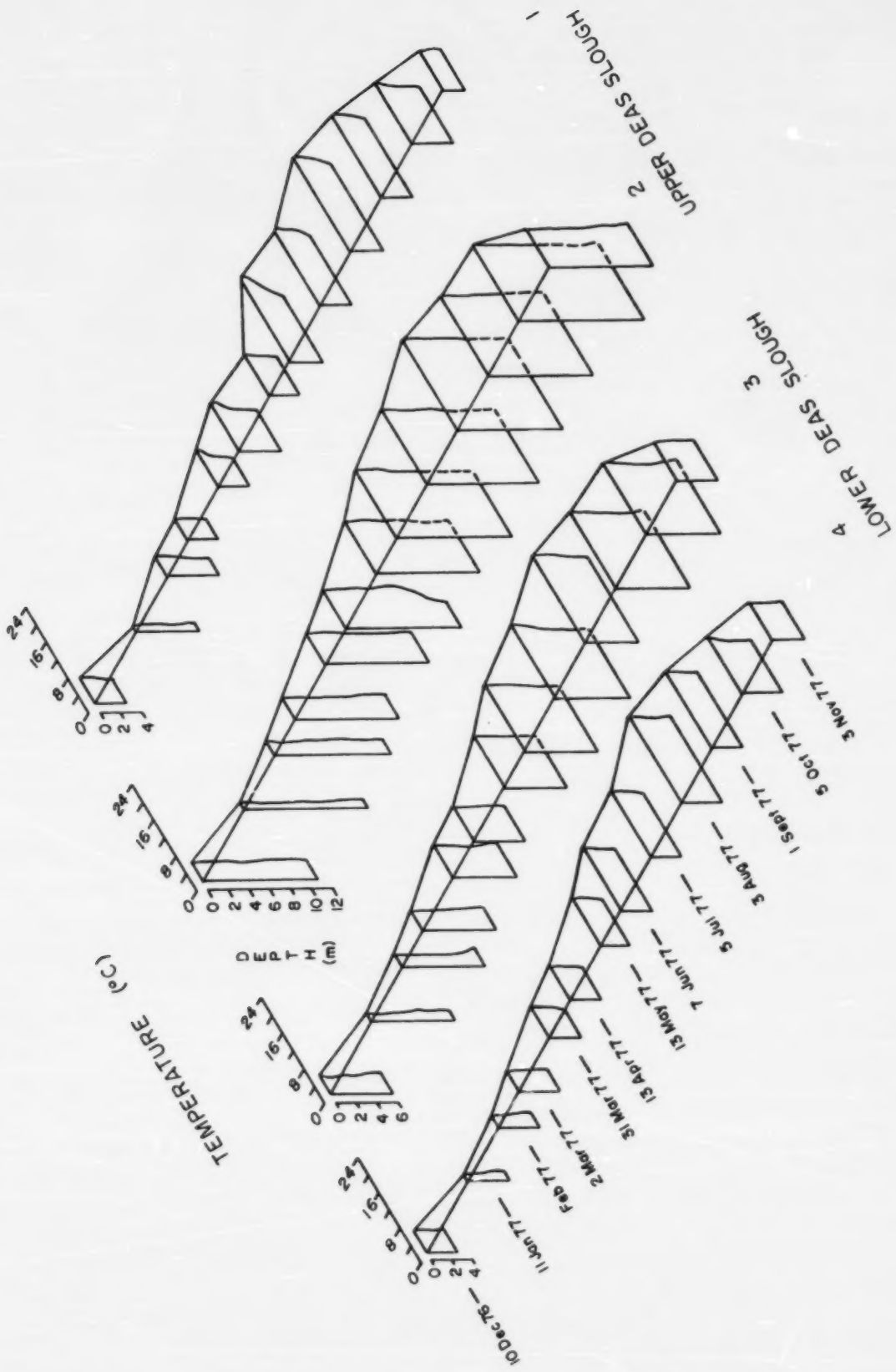

1
UPPER DEAS SLOUGH
2
LOWER DEAS SLOUGH
3
4
TEMPERATURE (°C)
DEPTH (m)
10 Dec 76
11 Jan 77
Feb 77
2 Mar 77
31 Mar 77
13 Apr 77
13 May 77
7 Jun 77
5 Jul 77
3 Aug 77
1 Sept 77
5 Oct 77
3 Nov 77

FIGURE 6. Temporal changes in mean salinity values (‰) recorded at 0.5m depth, in two regions of Deas Slough and in the Ladner Reach sampling zone.

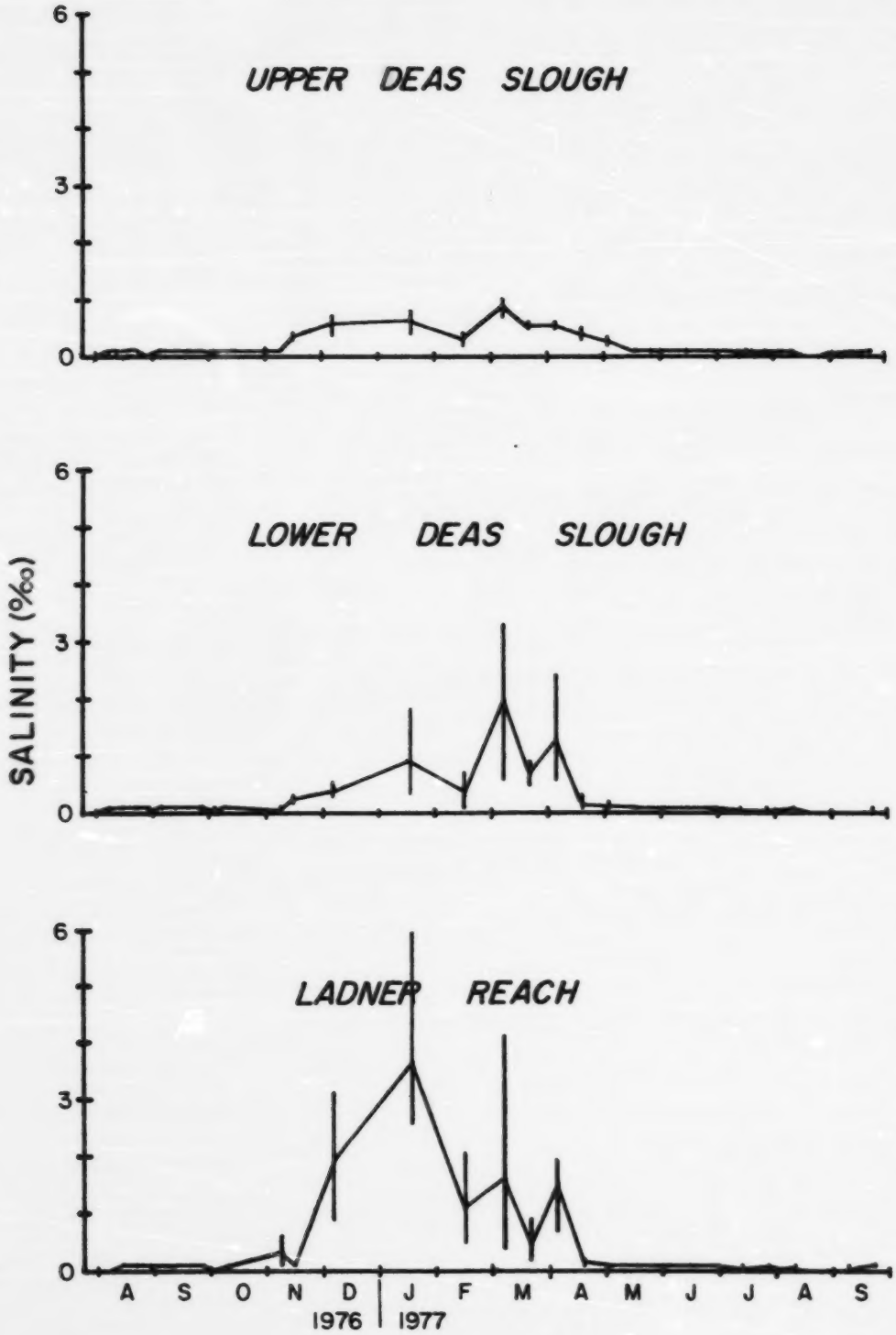

UPPER DEAS SLOUGH
LOWER DEAS SLOUGH
LADNER REACH
SALINITY (‰)
6
3
0
A S O N D J F M A M J J A S
1976 1977

FIGURE 7. Isometric-orthographic projection of salinity data collected at 4 sites in Deas Slough.

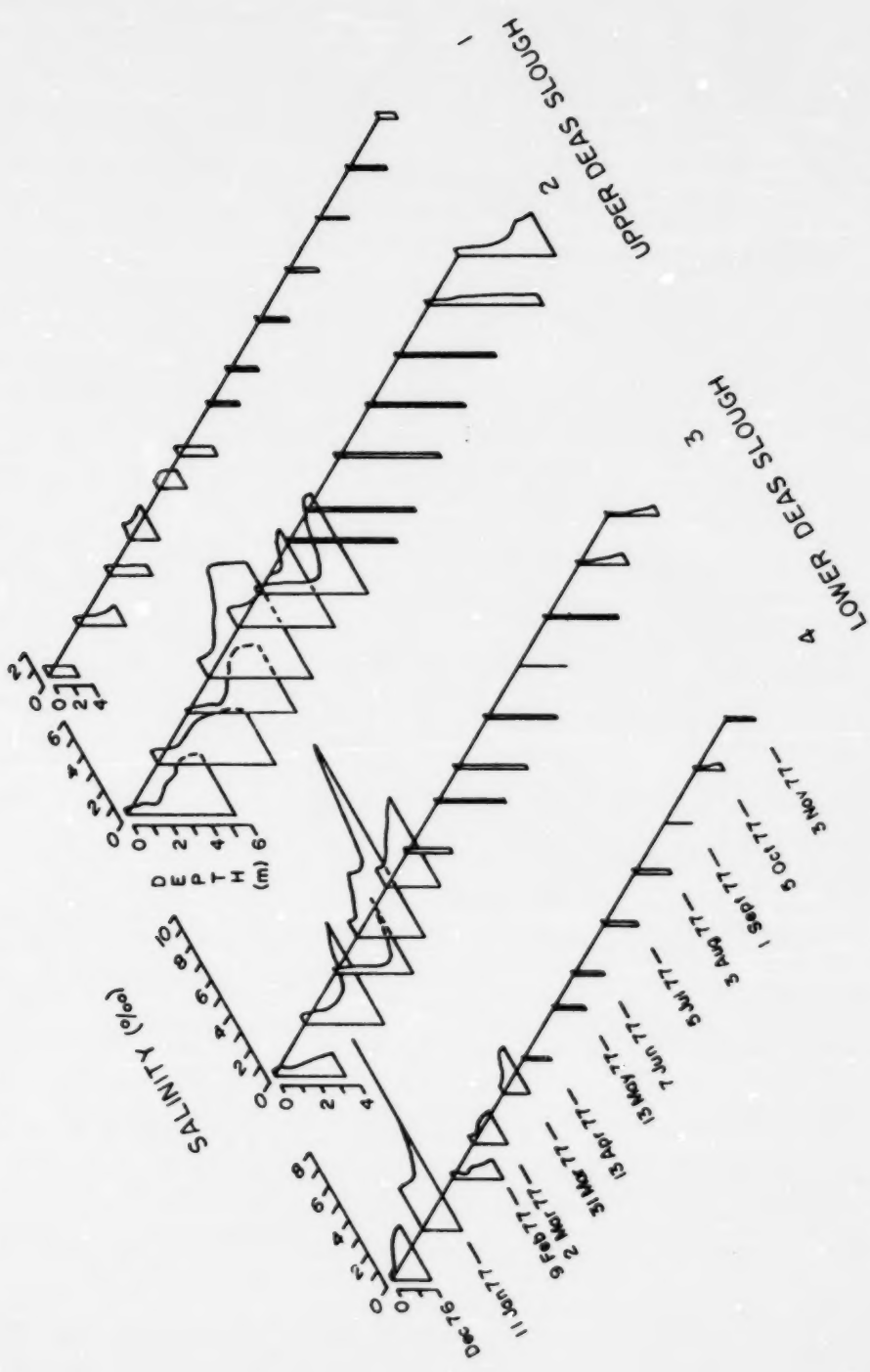

UPPER DEAD SLOUGH
LOWER DEAD SLOUGH
1
2
3
4
DEPTH (m)
SALINITY (o/oo)
3 Nov 77
5 Oct 77
1 Sept 77
3 Aug 77
5 Jul 77
7 Jun 77
13 May 77
13 Apr 77
31 Mar 77
2 Mar 77
9 Feb 77
11 Jan 77
Dec 76

FIGURE 8. Temporal changes in mean dissolved oxygen values (% of air saturation) recorded at 0·5m depth, in two regions of Deas Slough and in the Ladner reach sampling zone.

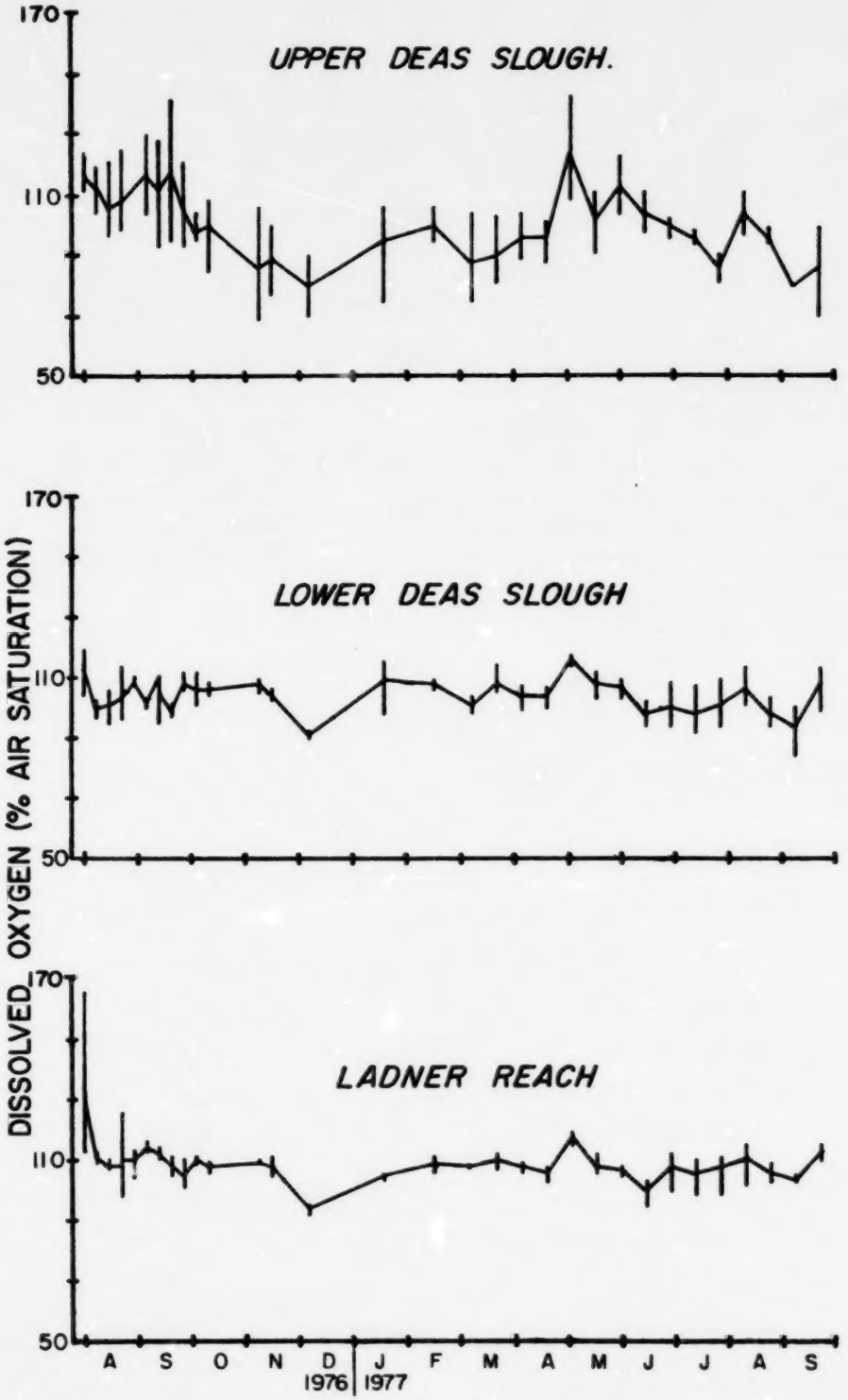

UPPER DEAS SLOUGH.
LOWER DEAS SLOUGH
LADNER REACH
DISSOLVED OXYGEN (% AIR SATURATION)
170
110
50
A S O N D J F M A M J J A S
1976 1977

FIGURE 9. Isometric-orthographic projection of dissolved oxygen data collected at 4 sites in Deas Slough.

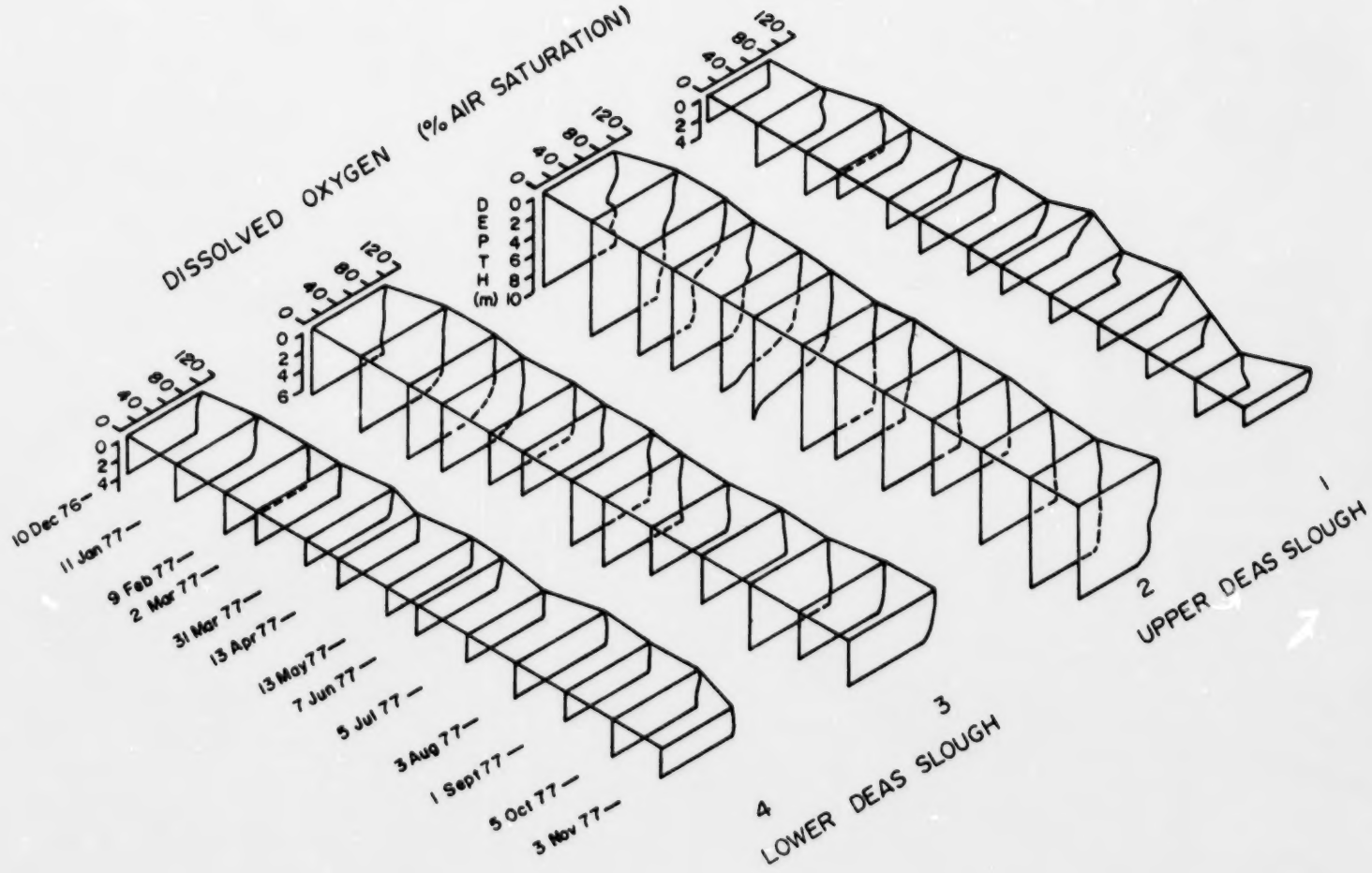

DISSOLVED OXYGEN (% AIR SATURATION)
0 40 80 120
DEPTH (m)
0 2 4 6 8 10
10 Dec 76
11 Jan 77
9 Feb 77
2 Mar 77
31 Mar 77
13 Apr 77
13 May 77
7 Jun 77
5 Jul 77
3 Aug 77
1 Sep 77
5 Oct 77
3 Nov 77
1
2
3
4
UPPER DEAS SLOUGH
LOWER DEAS SLOUGH

FIGURE 10: Temporal changes in mean pH values recorded at 0·5m depth, in two regions of Deas Slough and in the Ladner Reach sampling aone.

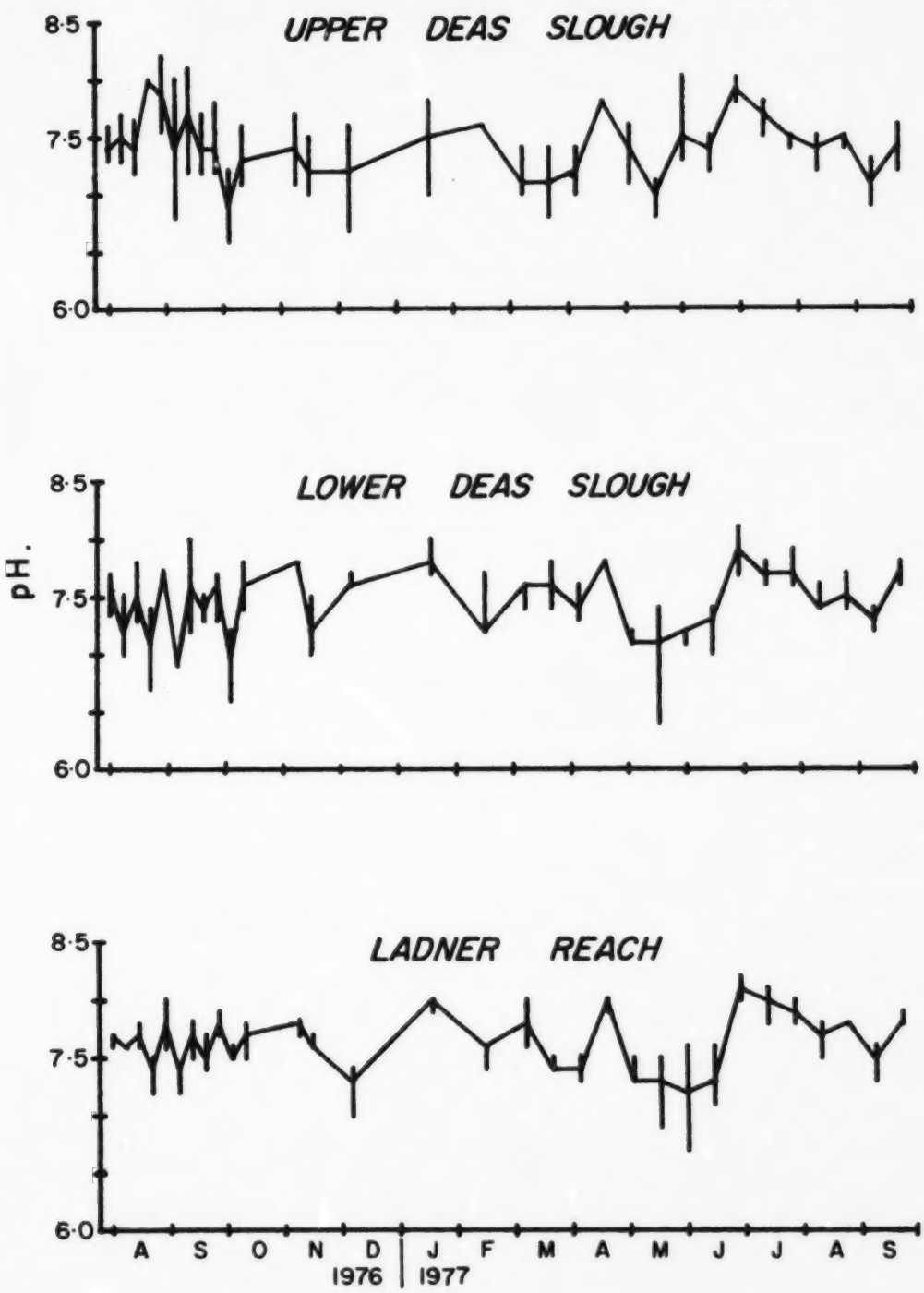

UPPER DEAS SLOUGH
LOWER DEAS SLOUGH
LADNER REACH
pH.
8·5
7·5
6·0
A S O N D J F M A M J J A S
1976
1977

FIGURE 11: Temporal changes in mean oxidation-reduction potential values (mV) recorded at 0·5m depth, in two regions of Deas Slough and in the Ladner Reach sampling Zone.

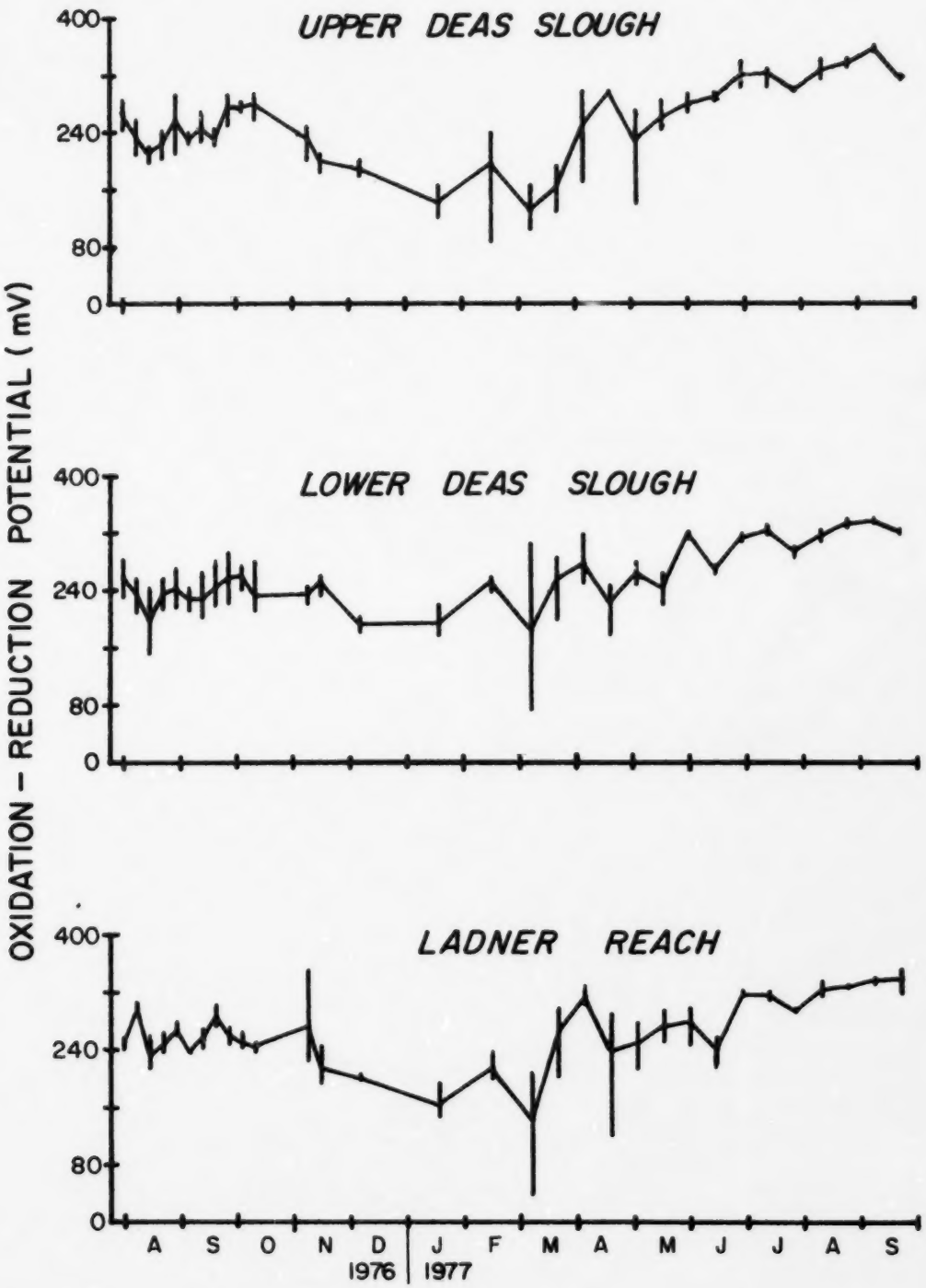

UPPER DEAS SLOUGH
LOWER DEAS SLOUGH
LADNER REACH
OXIDATION - REDUCTION POTENTIAL (mV)
400
240
80
0
A S O N D J F M A M J J A S
1976
1977

FIGURE 12: Isometric-orthographic projection of oxidation-reduction potential data collected at 4 sites in Deas Slough.

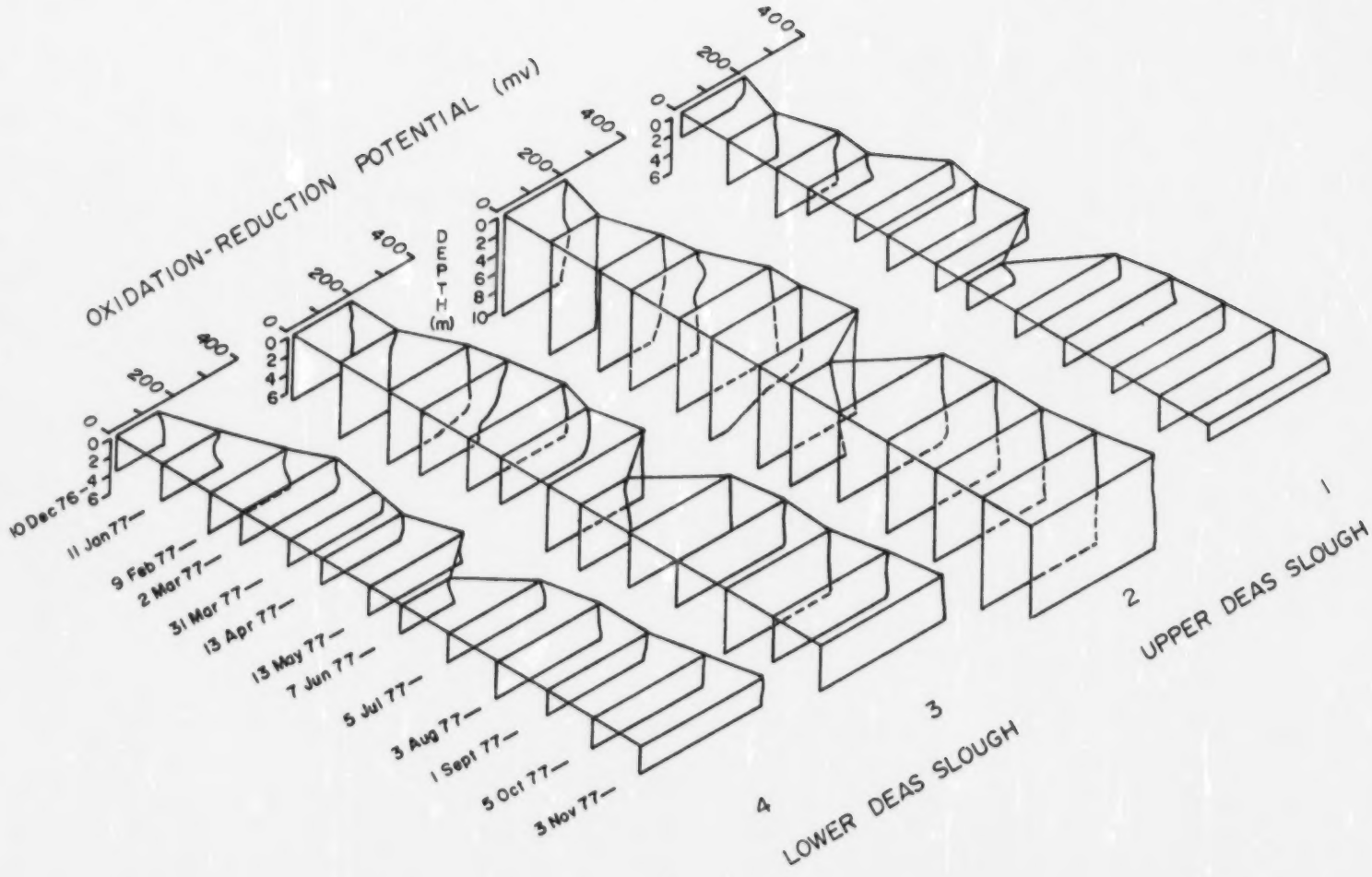
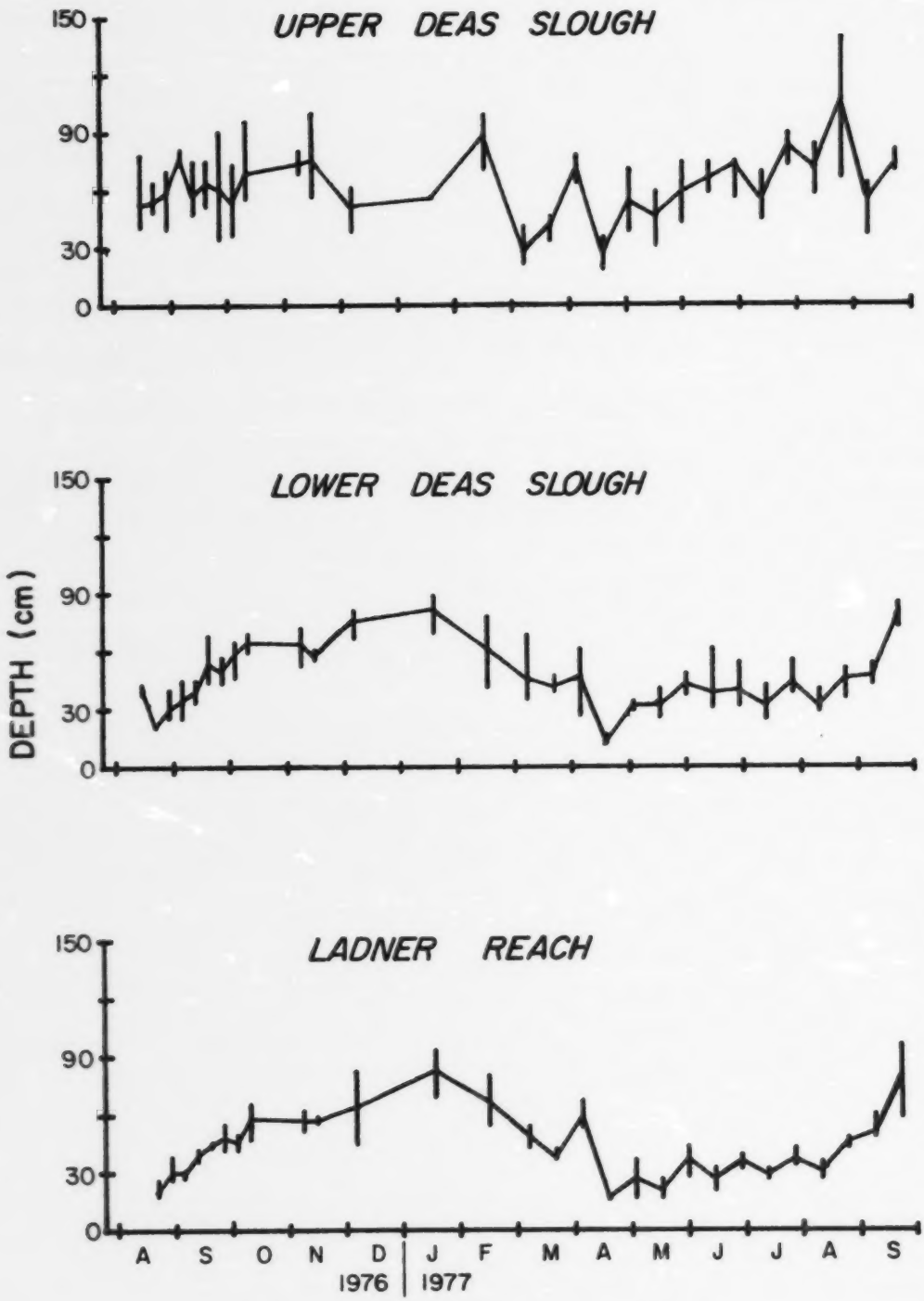

OXIDATION-REDUCTION POTENTIAL (mv)
DEPTH (m)
0
200
400
0
2
4
6
8
10
10 Dec 76
11 Jan 77
9 Feb 77
2 Mar 77
31 Mar 77
13 Apr 77
13 May 77
7 Jun 77
5 Jul 77
3 Aug 77
1 Sept 77
5 Oct 77
3 Nov 77
1
2
3
4
UPPER DEAS SLOUGH
LOWER DEAS SLOUGH

FIGURE 13: Temporal changes in mean Secchi disc visibility values recorded at 0.5 m depth, in two regions of Deas Slough and in the Ladner Reach sampling zone.


UPPER DEAS SLOUGH
LOWER DEAS SLOUGH
LADNER REACH
DEPTH (cm)
150
90
30
0
A S O N D J F M A M J J A S
1976 1977